

# Effects of Remaining Hair Cells on Cochlear Implant Function

## 6th Quarterly Progress Report

Neural Prosthesis Program

Contract N01-DC-2-1005

*(Quarter spanning October to December, 2003)*

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January 30, 2004

File: N01-DC-2-1005QPR06.PDF  
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N01-DC-2-1005QPR06  
Neural Prosthesis Program

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## 1. Summary of Activities in This Quarter

During the sixth quarter of this contract (October 1 through December, 2003), we accomplished the following:

1. We attended and presented progress reports at the NIH Neural Prosthesis Workshop, Bethesda, MD (Oct. 21-23).
2. One member of our group (K.N.) attended the 33rd Annual Meeting of the Society for Neuroscience in New Orleans (Nov. 8 - 12) and presented material related to the guinea pig experiments on combined electric pulse-train and acoustic noise stimulation (see Presentations and Manuscripts).
3. Our findings on reversible hair-cell effects (evidenced through the use of furosemide) were published in *Hearing Research* (see Presentations and Manuscripts).
4. We submitted a manuscript on the feasibility of using University of Michigan thin-film electrodes for auditory nerve-trunk recordings.
5. We replaced all experimental equipment into the newly installed double-walled sound booth and readied the set up for single-fiber studies. This entailed efforts to reduce unacceptable levels of low-frequency vibrations of the booth floor that were apparent in the first single-fiber experiments of this quarter (fiber hold times were very short). We attributed this problem to increased mass in the room and larger floor area. The problem was ameliorated by adjusting pressurized vibration dampers beneath the booth and adding cushioning material to the experimental table.
6. We performed 6 additional acute guinea pigs experiments, 3 of which maintained acoustic sensitivity within 20 dB of pre-operative levels and yielded useful data on the effects of combined wide-band acoustic noise and electric pulse-train stimuli on the compound action potential response. Data from those subjects are consistent with the findings presented in the previous (fifth) report. The additional data are being used to improve the accuracy of our characterizations of adaptation and recovery time constants in a manner appropriate for publication as well as expanding the experimental manipulations to include assessing the effects on single electric-pulse stimuli presented at different times relative to the acoustic signal.
7. We completed analysis of single-fiber data of one preparation (D15) that involved the use of longer-duration (>100 ms) acoustic stimuli. We performed single-fiber experiments on four cats during this quarter. In two of the four cases, threshold shifts in acoustic sensitivity greater than 30 dB occurred after the cochleostomy and monopolar electrode insertion, while thresholds were preserved to within 10 dB in the other two. To date, we have collected single-fiber data to the longer-duration acoustic stimuli from three cats (D15, D18, D21).
8. We finally note that scheduling cat experiments has been complicated by vendor problems. Within the past year, we have been instructed by the University Animal Care Unit that 3-month, and now, 6-month notice must be given to procure each cat. As it is difficult to predict personnel schedules that far in advance, this will likely require pre-booking cats at regular intervals to avoid lost experiment opportunities. Thus, animal care costs (e.g., caging per diems) will likely increase in order to maintain a regular experiment schedule, as will the ability to make adjustments to the schedule.

## **2. Focus Topic: Acoustic-electric interactions observed at the single-fiber level using longer duration stimuli**

### **2.1. Introduction**

In previous work (see QPR #4) we presented single-fiber data dealing with acoustic-electric interactions observed in response to acoustic wideband noise and either single electric pulses or 100 ms duration electric pulse trains. That work demonstrated significant effects of acoustic noise on the response to electric trains during noise presentation, but little, if any, effect in the interval after the offset of the acoustic noise. Our analogous studies of the guinea pig ECAP (see QPR #5) have indicated that adaptation to the combined stimuli occurs over durations greater than 100 ms and that interesting post offset (or “residual”) effects can be observed. Furthermore, the ECAP results indicate that these residual effects are more evident in cases where the acoustic stimulus is presented with durations greater than 100 ms. As indicated in earlier reports, we sought to examine these effects at the single-fiber level.

Compared to our previous single-fiber work, this effort is particularly challenging. As noted above, some preparations lose sensitivity to acoustic stimulation, presumably due to trauma caused by the cochleostomy and insertion of a small (0.4 mm) monopolar ball electrode. Perhaps more critically, data collection requires relatively long fiber contact time, as, for each combination of electric and acoustic levels, we collect three sets of responses: (1) to electric train alone, (2) to acoustic burst alone, and (3) to the combined stimuli. In several recent animals we have been attempting to record parametric data for different noise/pulse train durations with a single fiber. To accomplish this, we use long inter-stimulus intervals (e.g., 400 - 800 ms) to prevent significant changes in baseline sensitivity across the repeated stimulus presentations, further increasing the demands on fiber-contact time. Collection of complete data sets across all parameters (acoustic level, electric level, and acoustic stimulus duration) has been particularly challenging. We continue to collect additional data on these within fiber and will include them in future reports.

This report presents analysis for fibers, primarily for D15, in which we used longer (200 ms) noise bursts to further explore adaptation and noise-offset effects. As noted above, this duration has demonstrated significant amplitude changes in guinea pig ECAP recordings both during acoustic noise and after noise offset.

### **2.2. Methods**

The methods of data collection are essentially the same as those described in QPR #4 of this contract. The primary difference was that in the data described here, the duration of the acoustic noise was 200 ms and the electric pulse train duration was 400 ms. Compared to our previous experiments, these durations more closely match the conditions under which we have observed significant ECAP effects after the offset of the noise stimulus (QPR #3). As in those studies, 40  $\mu$ s cathodic-first biphasic pulses were used and the inter-pulse interval was fixed at 320  $\mu$ s for a pulse rate 250 pps. This rate enabled us to unambiguously resolve both the “ $\alpha$ ” (direct) and “ $\beta$ ” (electrophonic) responses. The noise was gated on 50 ms after onset of the electric pulse train. This allowed us to evaluate responses to the electric pulse train before, during and after the noise presentation.

We have also changed the data collection protocols relative to those used in the analysis of single-fiber data used in the group analyses of QPR #4. The new data collection protocol includes collection of responses to the noise stimulus presented alone, interleaved with presentations of the electric pulse train

alone, and the electric pulse train and imbedded noise. This change allows us to monitor the response to the noise throughout the experiment to assess non-stationary effects that could bias our results. Finally, we have also initiated a procedure using tonal stimulation to evaluate the response across frequency in order to assess best frequency of each fiber when time allows. Response to 30-50 stimulus presentations were used to generate the histograms shown in this report. Acquisition of responses to a single stimulus condition would typically require a minimum of 2-2.5 minutes.

All response traces were saved and analyzed offline. Removal of stimulus artifact was accomplished using an artifact templating method described previously. We evaluated both time of each action potential (based on the peak of the action potential) as well as the amplitude of the action potential (measured from peak to following afterhyperpolarization). The times relative to stimulus onset were used to generate histograms shown in this report.

### 2.3. Results

#### *Effect of longer-duration (200-ms) noise on response to an electric pulse train*

Data from a typical fiber are presented in Figure 1. The upper panel shows the response to the 400 ms electric pulse train presented alone. The peaks in the histogram demonstrate the responses phase-locked to the electric pulses separated by 4 ms. The variability in the peak amplitudes across pulse presentations are likely due, in part, to the relatively low number of stimulus presentations (50). However, as noted later, there is a general trend of reduced spike probability over the pulse train. The middle panel plots the response to the noise burst presented alone. A clear onset effect is noted, typical of acoustic responses, decaying to a steady-state response rate. The response to the “noise + pulse train” (bottom panel) demonstrates a lack of clear peaks in the response during the noise burst and a decrease in the magnitude of the electrically induced peaks during the period after noise onset.

These example histograms demonstrate several features of the single-fiber response that we would like to stress. As noted in our previous report, the acoustic noise can significantly decrease the degree to which responses are locked to the pulse train. That effect is in some way analogous to the acoustic masking of noise on tone-burst responses that was described by Kiang et al. (1965). In addition, after offset of the acoustic noise, we observe decreases in the response to the electric pulses, presumably due to adaptation of the neurons to the acoustic stimulation. This clear decrease is in contrast to the observations reported in QPR #4 for 100-ms noise bursts. This decrease may be analogous to post-stimulus acoustic effects seen reported by Smith (1977). We note, however, that both the simultaneous and post-noise offset effects observed here affected the direct ( $\alpha$ ) electrical responses and are therefore not hair-cell or synaptically mediated.

In order to summarize response properties from a number of fibers, we have analyzed the responses over four time intervals relative to stimulus onset. These intervals are shown below the histograms of Figure 1 and are described here:

Interval	Window (ms)	Description of analysis window
1	0 – 50	Immediately after onset of electric train
2	61 – 110	Shortly after acoustic onset (chosen to avoid onset effects)
3	201 – 250	Over final part of noise burst, to assess “steady state” response
4	261 – 310	Over period after acoustic offset

These intervals are similar, but wider than those used in the previous analysis of QPR #4. Longer windows were chosen in an effort to increase total spike counts and temporal resolution of computed period histograms. For each of the four intervals, responses to each of the three stimulus conditions (Electric alone, Acoustic alone, Electric+acoustic) were analyzed.

Both total spike count and vector strength relative to the period of the pulse train stimulus were assessed over each interval. In each case, we characterized the effect of noise by plotting measures (e.g., spike count, vector strength, spike amplitude) as ratios of the response obtained in the electric+noise condition to the response obtained in the electric alone condition. Spike count ratio characterizes the change in overall activity due to the combined acoustic+electric stimulus. Vector strength ratio was calculated in each stimulus interval in order to assess the degree to which noise presentation has an effect on the response to the electric pulses.

Figure 2 plots data from 18 fibers for which we have collected data at a high noise level (96 dB SPL). In each case, the electric pulse level was adjusted so that the fiber responded within its dynamic range (i.e., firing efficiency < 100%) to avoid saturation effects that could mask acoustic-electric interaction effects. The upper panel plots spike count ratio versus the analysis window interval; the lower panel plots vector strength ratio for the 18 fibers. As expected, these ratios are generally close to unity in interval 1, as that analysis period precedes noise onset.

The spike count ratio increases significantly during the noise presentation (intervals 2 and 3) due to the increased response to the noise burst. During the period after noise offset (interval 4), the spike count tended to decrease significantly, suggesting that the noise has a residual effect, presumably adapting the fiber and decreasing the responsiveness to the electric pulses. A unpaired t-test between counts in interval 4 and interval 1 indicates that the spike ratios in interval 4 are significantly lower than in the control interval ( $T=-3.48$ ,  $p=0.0014$ ,  $d.f.=34$ ). Group data analysis of single-fiber responses to shorter-duration (100 ms) noise burst showed a much smaller noise-offset effect (QPR #4), suggesting a dependence on the duration of the acoustic stimulus.

The vector strength ratio tends to be significantly less than one during noise presentation (intervals 2 and 3), indicating significantly decreased phase locking the pulse train, consistent with the data presented in QPR #4. The measures of vector strength after noise offset show, in some cases, a decreased response while other fibers show an increased response. This variability may be related to the more complex recovery effects that we have reported in the ECAP for similar stimuli (QPR #5). In those responses, we have, under different stimulus conditions, observed ECAP amplitude increases, decreases, and even a combination of changes during the post-noise recovery period. Ongoing studies of ECAP acoustic/electric interactions are directed (in part) at determining the degree to which stimulus parameters of stimulus levels and acoustic duration are responsible for these post-noise effects.

### *Effects of noise level*

In several fibers, we have measured responses over a range of acoustic noise levels. Data from eight fibers are plotted in Figure 3. In each case, the ratio of vector strength (electric + acoustic relative to electric alone) is plotted as a function of analysis interval. Plots show characteristics similar to those in Figure 2. We note in these cases, however, that the effectiveness of acoustic stimulation tends to be dependent on noise level, i.e., higher noise levels result in greater decrease in vector strength. Also, there are several fibers where relatively moderate acoustic levels (i.e., 66 and 76 dB SPL) show significant effects on vector strength. In particular, fiber D15-1-2 (left column, top panel) shows a high degree of

acoustic sensitivity, suggesting that low-level noise may have a significant effect on electric response in some fibers.

#### *Relationship among response variables*

We have examined relationships among response variables in an initial effort to better understand some of the mechanisms underlying observed acoustic – electric interactions. We used the data from the 18 fibers represented in Figure 2 to assess the correlations among several of the measures in different stimulus intervals. Each of the following figures shows scatter plots evaluating the relationship between the specific response measures. In each case, we again use the ratio of the response to electric + acoustic condition relative to the response to electric-alone condition to assess acoustic-electric interactions.

Figure 4 shows a clear relationship between the decrease in vector strength after noise onset (interval 2) relative to the change in vector strength during the steady state response to the noise (interval 3), with a correlation coefficient of  $r=0.95$ . The decrease in vector strength is similar in the two intervals, consistent with observations made in QPR #4 showing that, at high noise levels, there was relatively little onset effect evident in the vector strength. We note that an onset effect on vector strength was observed in that previous work, when low-level acoustic stimuli were applied. This suggests that the acoustic effect on spike timing saturates at relatively low acoustic levels.

We also sought to determine whether or not single-fiber response measures obtained during simultaneous presentation of electric and noise stimuli were predictive of effects observed after noise offset. Figure 5 plots the ratio of vector strength in interval 4 relative to that in interval 2. No clear correlation is evident. This is perhaps not surprising, as vector strength has not demonstrated a consistent decrease in the post-noise interval (see Figure 2). It is more plausible that spike activity could be correlated between these two analysis windows. We therefore examined the relationship between the increase in firing rate during interval 2 (in response to the noise stimulus) and the decrease in response to the pulse in interval 4 (after noise offset). Figure 6 plots the ratio of the spike counts in interval 4 relative to the ratio of spike counts in interval 2. The plot shows a moderate negative correlation ( $r=-0.52$ ); that is, decreases in the post noise interval activity are correlated with increases in rate during noise presentation.

#### *Response to electric pulse train over time*

Our previous work with ECAP responses to pulse trains has demonstrated an interaction between hearing status and ECAP adaptation (Hu et al., 2003). We therefore examined single-fiber responses to electric pulse trains in fibers with acoustic sensitivity to assess adaptation effects. To evaluate these effects we used the same four analysis windows described in Figure 1. Using the same pool of 18 fibers (as in Figure 2), Figure 7 plots spike rate (upper panel), vector strength (middle panel) and spike amplitude (lower panel) as a function of analysis interval. To more easily compare data across fibers, we plot each variable relative to the value obtained in the first analysis interval. Spike rate shows a clear decrease over the time intervals in most fibers. Vector strength is relatively constant over the 200 ms period for most fibers. Average spike amplitude also shows relatively little change in response over time. We chose to examine spike amplitude effects as we have previously (Miller et al. 2001) observed reductions in spike amplitude within the relative refractory period of a fiber. As we observed no consistent change in spike amplitude while there were clear decreases in spike rate, we theorize that the mechanism of adaptation is different from that responsible for the decreased responsiveness during the relative refractory period.

We wish to note, however, that in one fiber analyzed to date, we observed clear changes in spike amplitude, as illustrated in Figure 8. The recorded traces in response to the first 12 pulses in the train are shown in the upper plot. These plots represent recordings after removal of the electrical stimulation

artifact; a small residual artifact can be seen in the traces before the large positive action potentials. The amplitude of the action potentials to each successive pulse in the train are decreased, at least over the first 5-6 pulses. In the panel below, the amplitudes of the action potentials recorded over the entire 400 ms pulse train are plotted. A clear decrease within the first 50 ms is evident, with spike amplitude reaching an approximate steady state over the remaining stimulus interval. In this case, the amplitude reduction is a significant fraction of the initial amplitude, suggesting that such fiber outputs could have altered central representation. It is not clear that we shall be able to collect sufficient data on such units to establish correlations with other fiber properties.

### *Effect of noise on period histograms to pulse trains*

The histogram in Figure 1 demonstrates several important features of the responses of nerve fibers to pulse trains and acoustic noise across the duration of the stimulus. We sought to examine the temporal properties of the response to each pulse in more detail and therefore calculated period histograms (relative to the pulse onset time) for each of the four intervals defined in Figure 1. For 50 stimulus presentations and twelve 4-ms periods within the 50 ms interval, we obtained 600 4-ms analysis periods for each analysis interval.

Typical period histograms for nerve responses are shown in Figure 9. Note that although the period is 4 ms, a range of only 0-2 ms is plotted in order to visualize details of the histogram peaks (no unusual features occurred in the last 2 ms). Histograms were calculated for the “electric+acoustic” stimulus (open circles) as well as for the electric alone condition (filled circles). Each column represents data for a particular interval, while each row represents data for a different noise level. We generally observed clear, narrow peaks in the response to the electric pulse trains alone. We also observed a decrease in the amplitude of the peak – and in many cases no clear peak -- in intervals 2 and 3 (i.e., with simultaneous noise presentation). Finally, we observed a clear decrease in peak of the histogram for high-level noise after noise offset (interval 4). In general, however, the shape of the histogram and width of the peak remains similar to the electric alone condition both during and after noise presentation.

The period histograms are useful in assessing modes of response at different latencies. Recently, we recorded from a number of fibers in another animal that was particularly sensitive to acoustic stimulation. Figure 10 plots period histograms from a fiber that showed a clear direct ( $\alpha$ ) and electrophonic ( $\beta$ ) response. Period histograms are plotted for the first three intervals and for 3 different levels of electric stimulation. At low levels (upper left plot), the shorter latency response is similar in amplitude to the longer-latency electrophonic response. At higher levels the earlier response becomes more dominant. We note also that there is an adaptation of the electrophonic response over the three time intervals. At the highest current level (1.15 mA), the response to electric alone (filled circles) shows an increase over time while the electrophonic response decreases. Finally, we note in this fiber a tendency to an increased width of the peak of the histogram as well as a decrease in peak value with the introduction of noise.

We have further investigated the changes in response latency over time by separating the responses into two temporal categories: direct (< 2 ms) and electrophonic (> 2 ms). These data represent responses to the pulse train alone. Probability of response in each interval is plotted as a function of stimulus pulse number in Figure 11. Each panel plots data for a different current level as noted in the histograms in Figure 10. These plots demonstrate in each case a decrease in electrophonic response over the first 10 pulses (40 ms). Over the same interval the direct response tends to increase. It is not clear what mechanism underlies the differential rates of adaptation, as hair-cell/synapse adaptation mechanisms could be proposed, as could more subtle interaction of refractory effects and spike timing.

## 2.4. Summary and conclusions

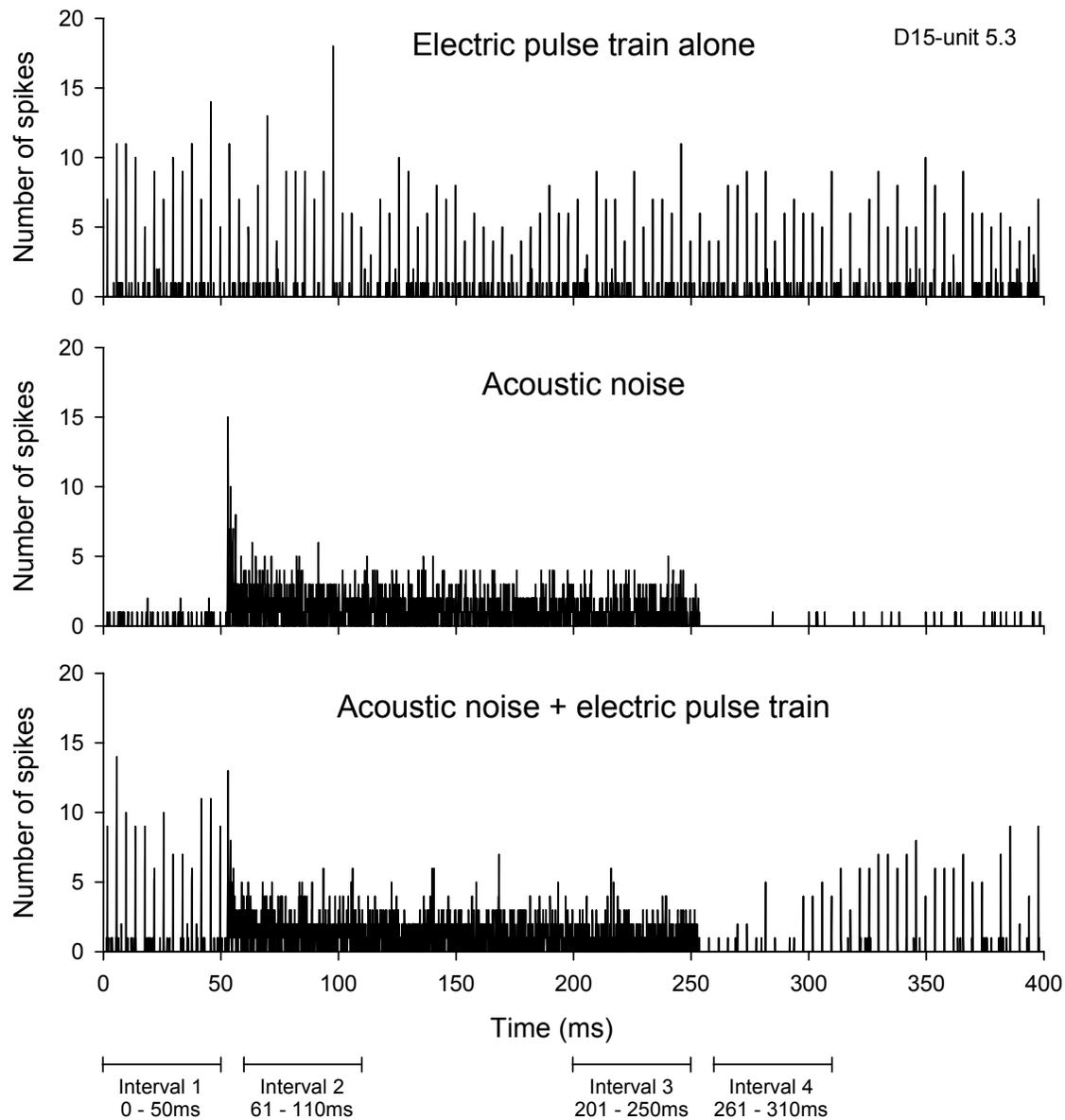
The primary purpose of the analyses presented in this report was to evaluate the effects of acoustic noise on the response to an electric pulse train after noise offset. As our previous report with 100-ms noise bursts did not show significant effects, we analyzed data a set with longer (200 ms) noise bursts and observed significant decreases in the spike rate after noise offset. The decreased responsiveness was as clear when the spike patterns in the same interval were analyzed as vector strength, suggesting that while the number of spikes was decreased, in many cases the synchrony was similar, or in some cases greater, than without acoustic stimulation.

In our parallel ECAP measures, we have under some conditions observed *increases* in the responsiveness in the time period after stimulus offset. Our working hypothesis has been that there are at least two possible mechanisms by which acoustic stimulation can affect the response to electrical stimulation. One may be the result of ongoing activity to the acoustic stimulus that desynchronizes and modifies (through refractoriness) the response to the electric pulses. A second mechanism may be due to the adaptation of the neuron to acoustic stimulation. After noise offset, the background activity would be expected to decrease, i.e., decreased spontaneous activity after stimulus offset. A consequence of that may be to increase synchronous response to electric pulses. Alternatively, adaptation due to the noise may have the effect of decreasing the responsiveness to electrical stimulation after noise offset. The decrease in spike count observed in Figure 2 for interval 4 suggests that the second mechanism contributes significantly to these response patterns. While the data relative to vector strength do not consistently demonstrate an increase, they are at least suggestive that in some cases there can be an enhancement of spike synchrony. We will be investigating this issue in the analysis of future data.

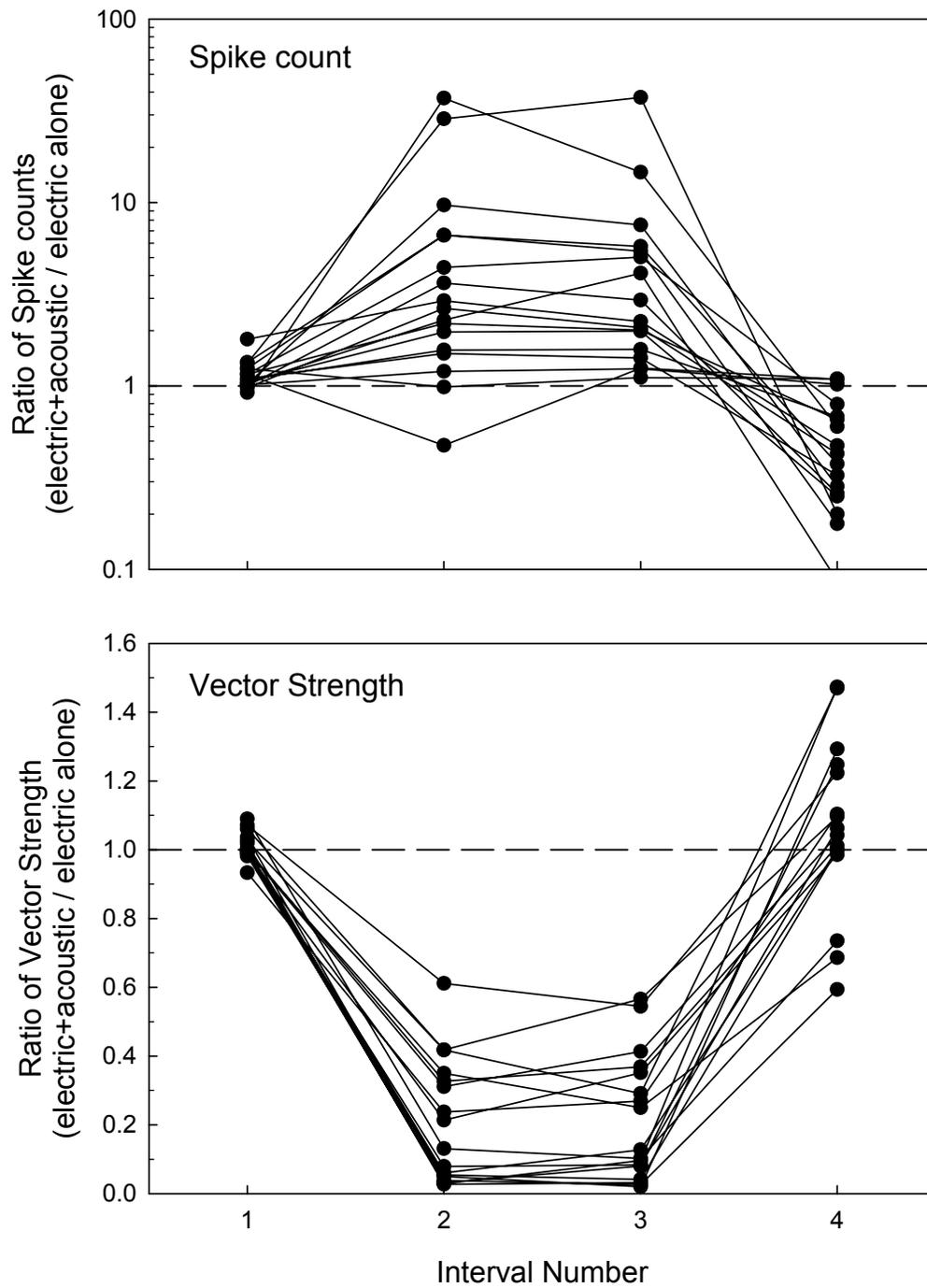
Our initial report concentrated on relatively high noise levels in order to maximize our ability to observe interactions between acoustic and electric stimulation. The effect of noise level observed in Figure 2 suggests that, at least in some cases, the effects may be present at low levels of noise as well. The dependence of the effects on noise level suggests that the degree of activity in response to the noise is an important factor in desynchronizing the response to the pulse train. Similarly, the effects reported in Figure 5 suggest that increased activity to the noise is responsible for the decrease in responsiveness to the pulse train in the interval after noise offset.

The preliminary analysis of the electrophonic responses in Figures 10 and 11 present several possibilities that we plan to investigate further. The changes in adaptation over time for the hair-cell mediated responses appear to be different than those due to direct stimulation. The relative effects of noise on the two response modes, both during and after the presentation of noise may also be expected to be different. While clear electrophonic responses are not reliably recorded in all fibers in a typical preparation, we plan to investigate these issues further when such fibers are encountered.

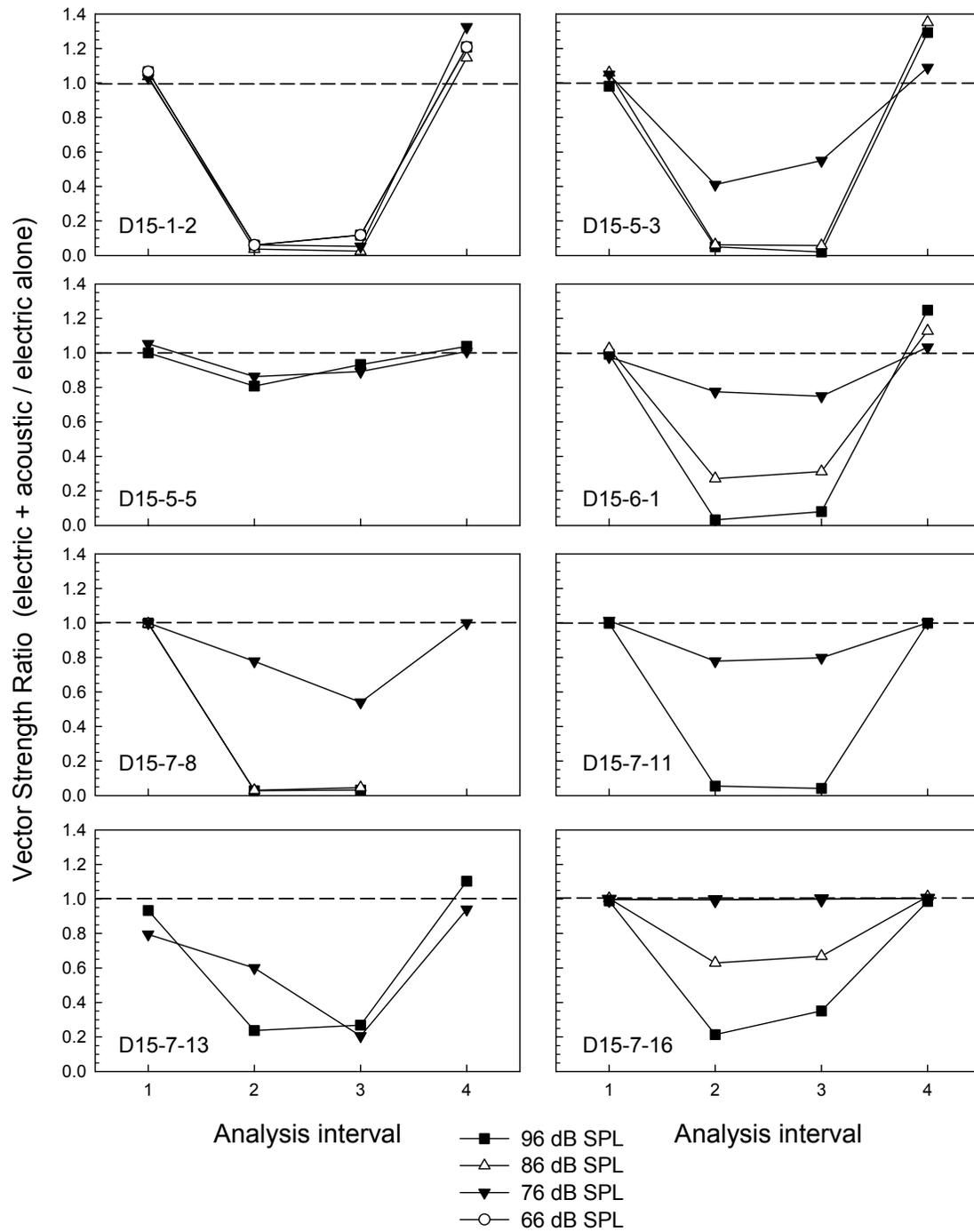
Our observation of differential rates of adaptation of the direct and electrophonic response has clear implications for the temporal coding of electrical stimuli, as they would give rise to transient changes in dominant intervals in the histogram and could lead to corresponding changes in perception. If this interaction is found to be a significant one in the fiber population, it would be interesting to determine the extent to which stimulation manipulation (both acoustic and electric) could control this source of temporal variation in the spike code.



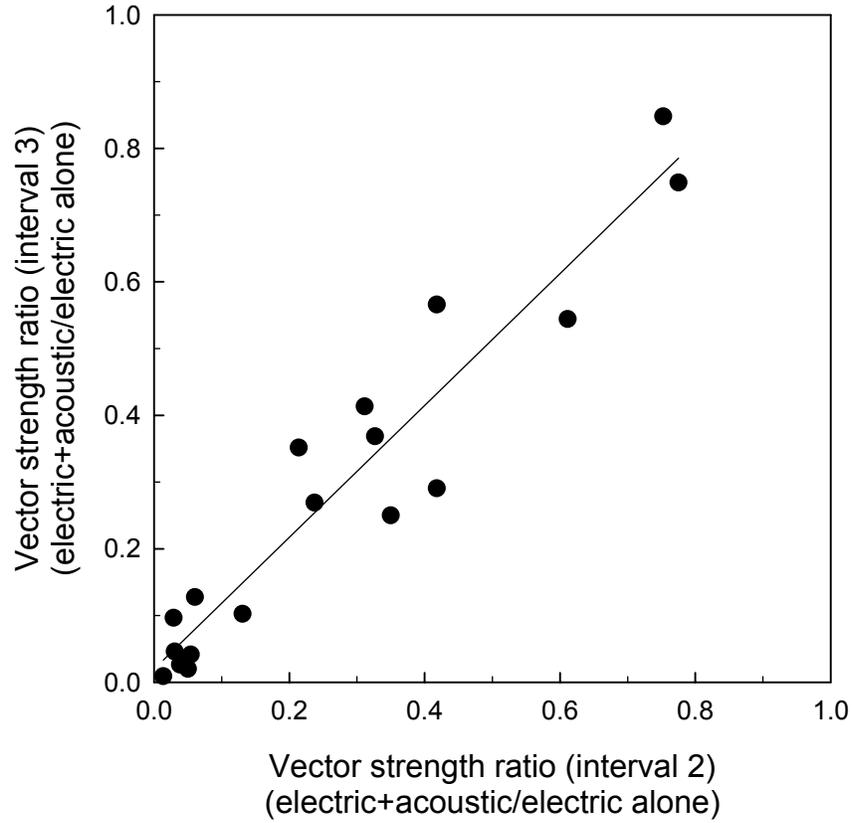
**Figure 1** PST histograms of the response to electric pulse trains (400-ms duration, 4-ms interpulse interval, 1.05-mA current level) and acoustic noise (96 dB SPL). The upper panel shows response to pulse train presented alone; the middle panel to the noise burst presented alone and the lower panel to the noise (from 50 ms to 250 ms) and pulse train presented simultaneously. The intervals (1-4) depicted at the bottom are those used for analysis in subsequent figures.



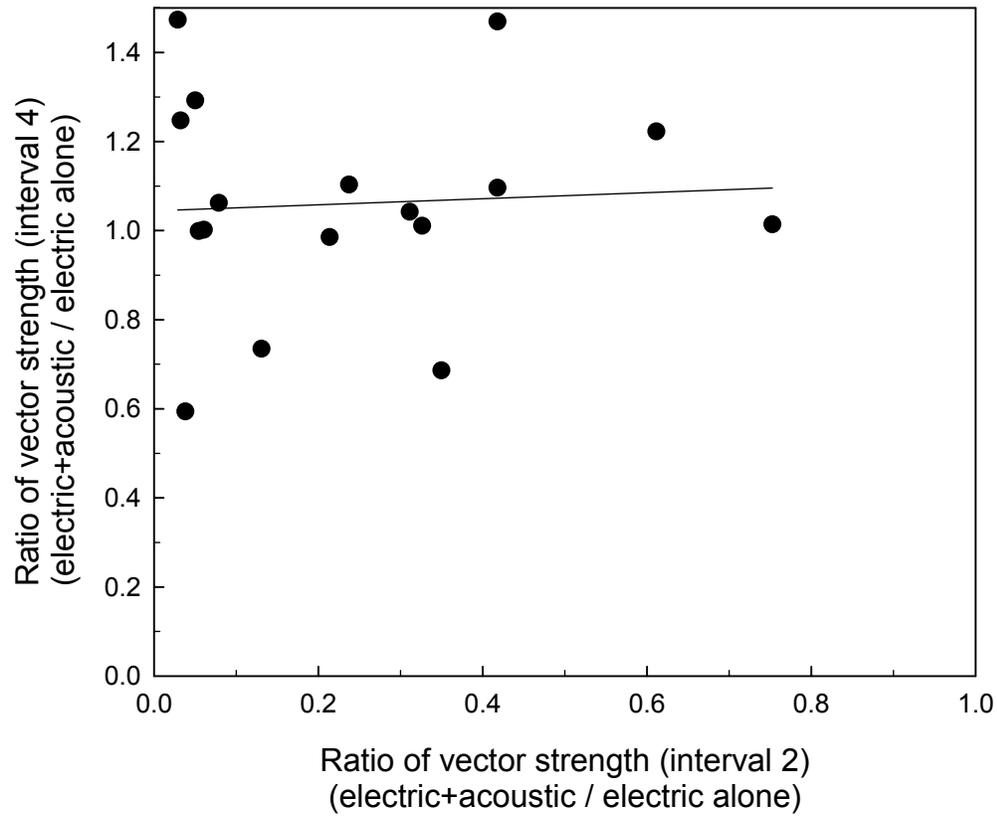
**Figure 2** Upper panel: Ratio of spike counts for electric+acoustic stimulation relative to electric alone is plotted as function of interval number as defined in Figure 1. Lower panel: Ratio of vector strength (electric+acoustic/electric alone) is plotted as function of analysis interval. Data are from 18 fibers, noise level is 96 dB SPL and current level for each fiber is at a level below saturation (firing efficiency  $<1$ ).



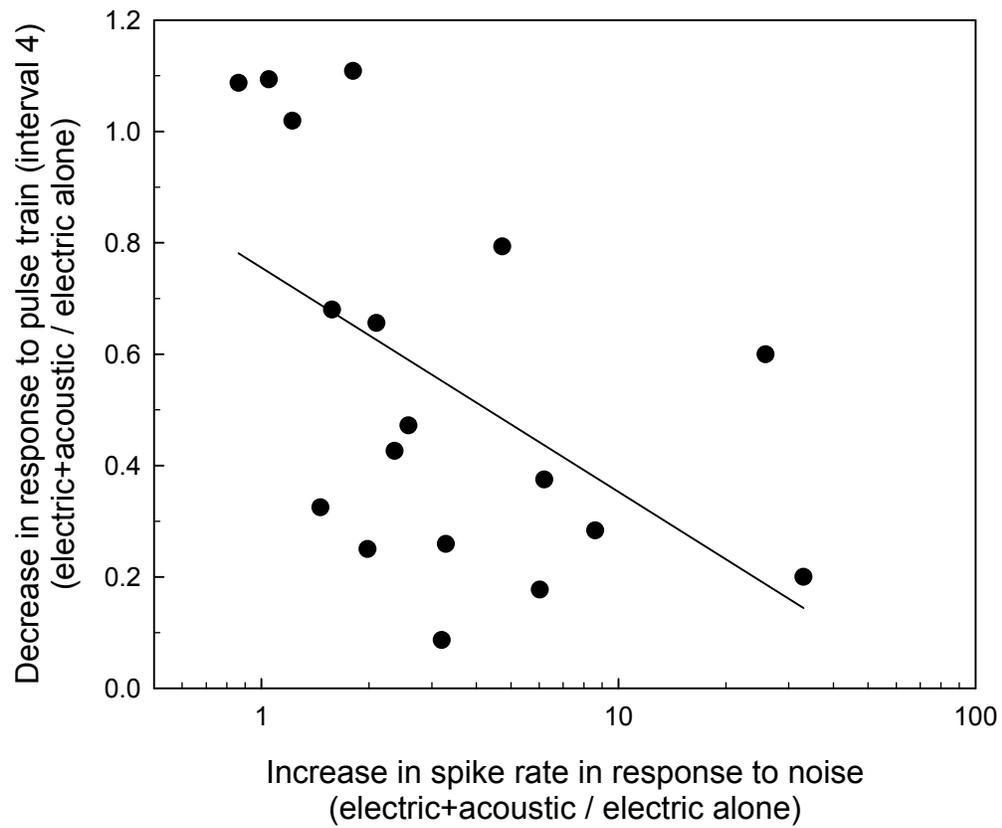
**Figure 3** Each panel plots the ratio of vector strength (acoustic + electric/ electric alone) as a function of analysis interval. Each panel illustrates data from a different fiber as indicated. The parameter in each plot is noise level as indicated in the legend.



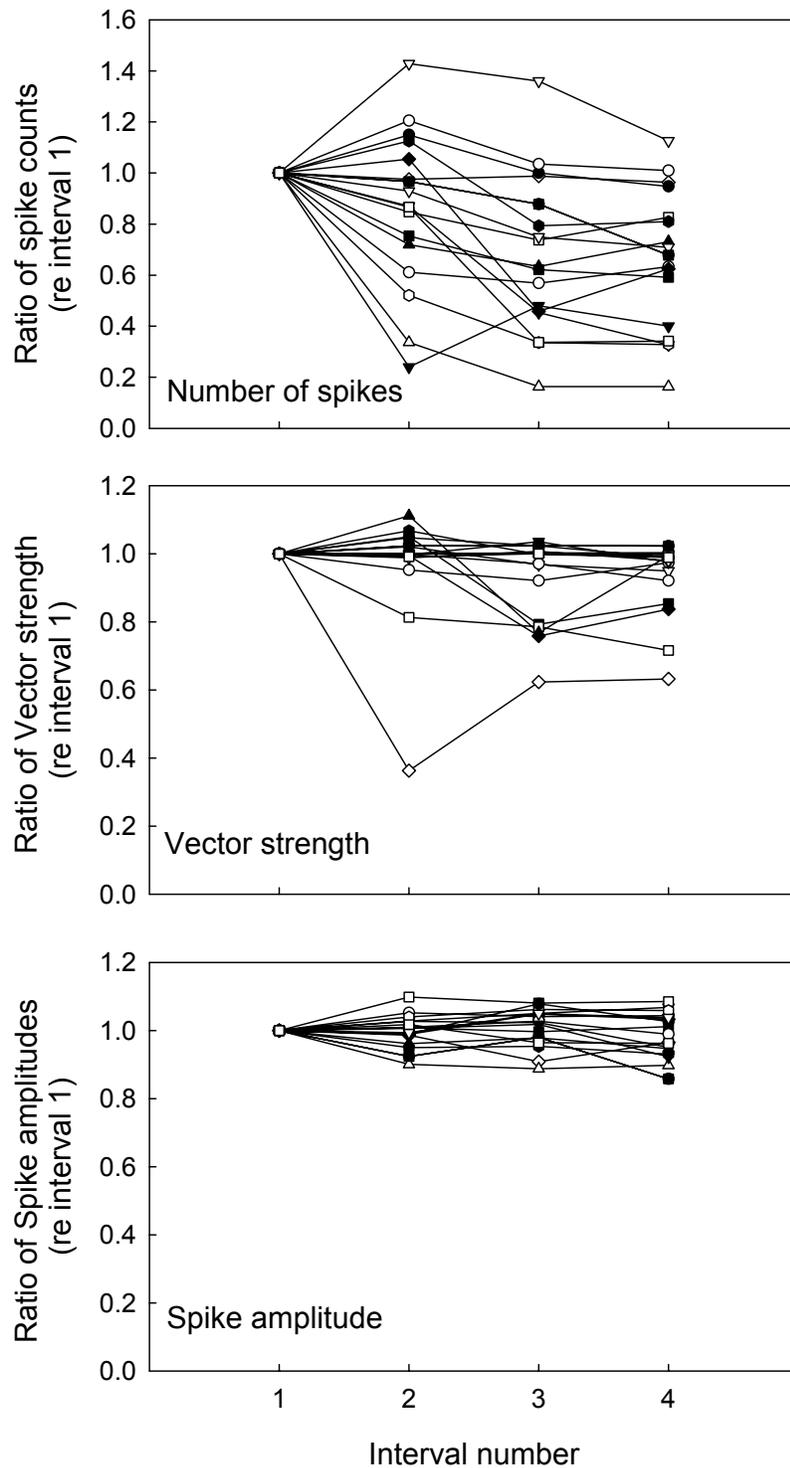
**Figure 4** The ratio of vector strength (acoustic + electric/ electric alone) in interval 3 is plotted as function of the same ratio in interval 2. Regression line is plotted ( $r=0.95$ ).



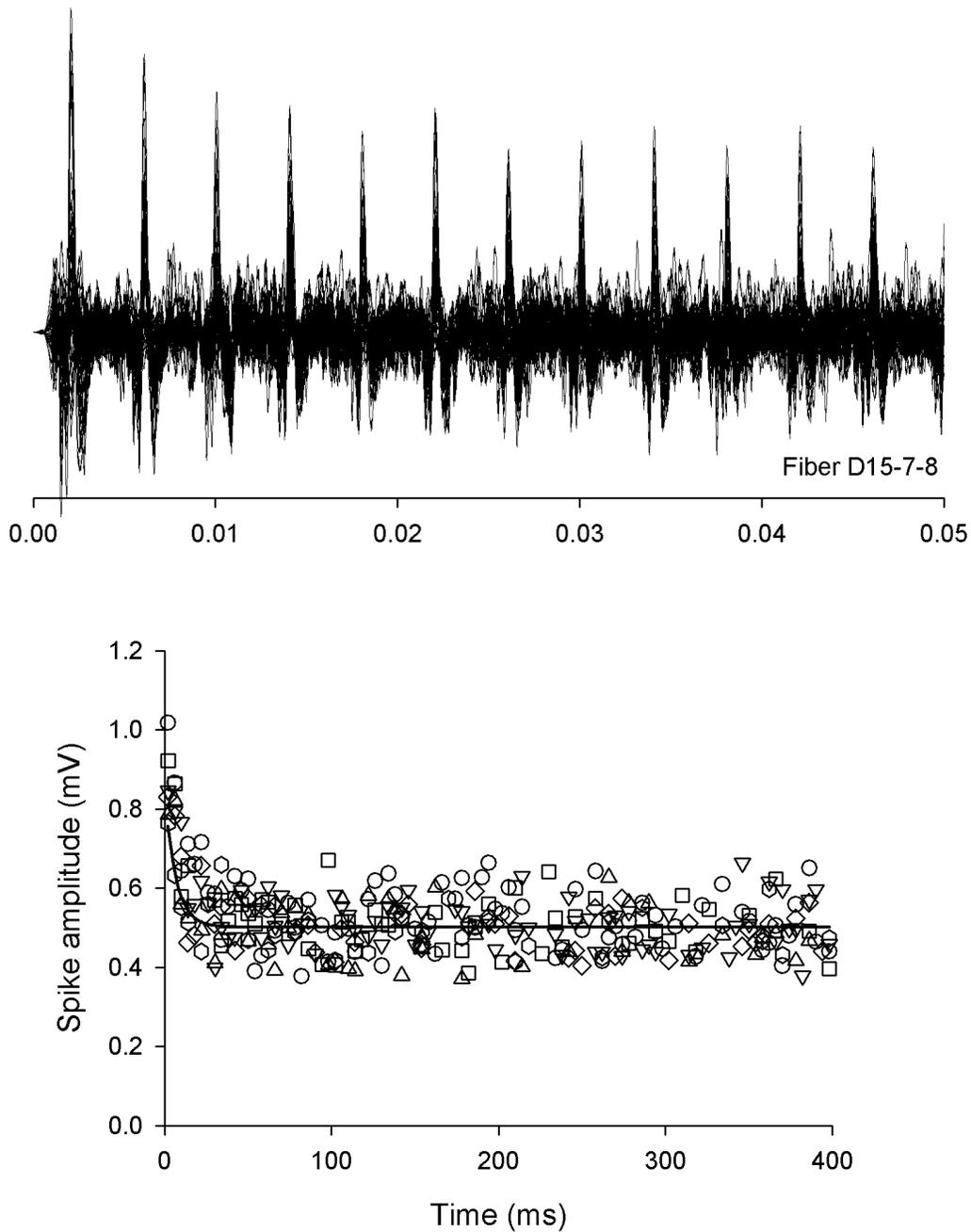
**Figure 5** The ratio of vector strength (acoustic + electric/ electric alone) in interval 4 is plotted as function of the same ratio in interval 2. Regression line is plotted ( $r=0.002$ ).



**Figure 6** The ratio of spike count (acoustic + electric/ electric alone) in interval 4 is plotted as function of the same ratio in interval 2. Regression line is plotted ( $r = -0.52$ ).

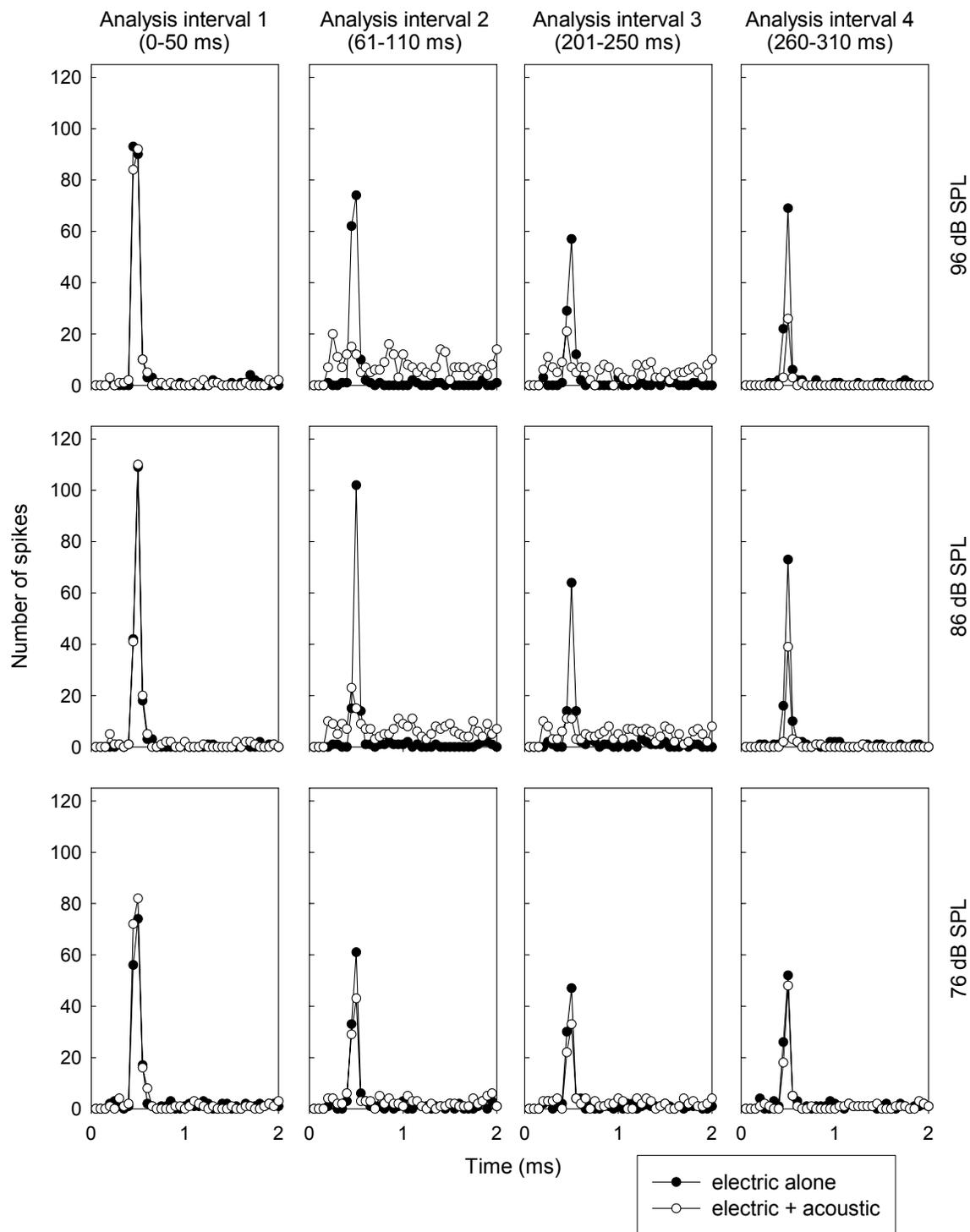


**Figure 7** Responses to electric stimuli presented alone are shown. Ratios of spike counts (upper panel), vector strength (middle panel) and spike amplitudes (lower panel) are calculated relative to the corresponding value in interval 1. Each parameter is then plotted as function of analysis interval. Data are plotted for the same fibers and stimulus levels as in Figure 2.

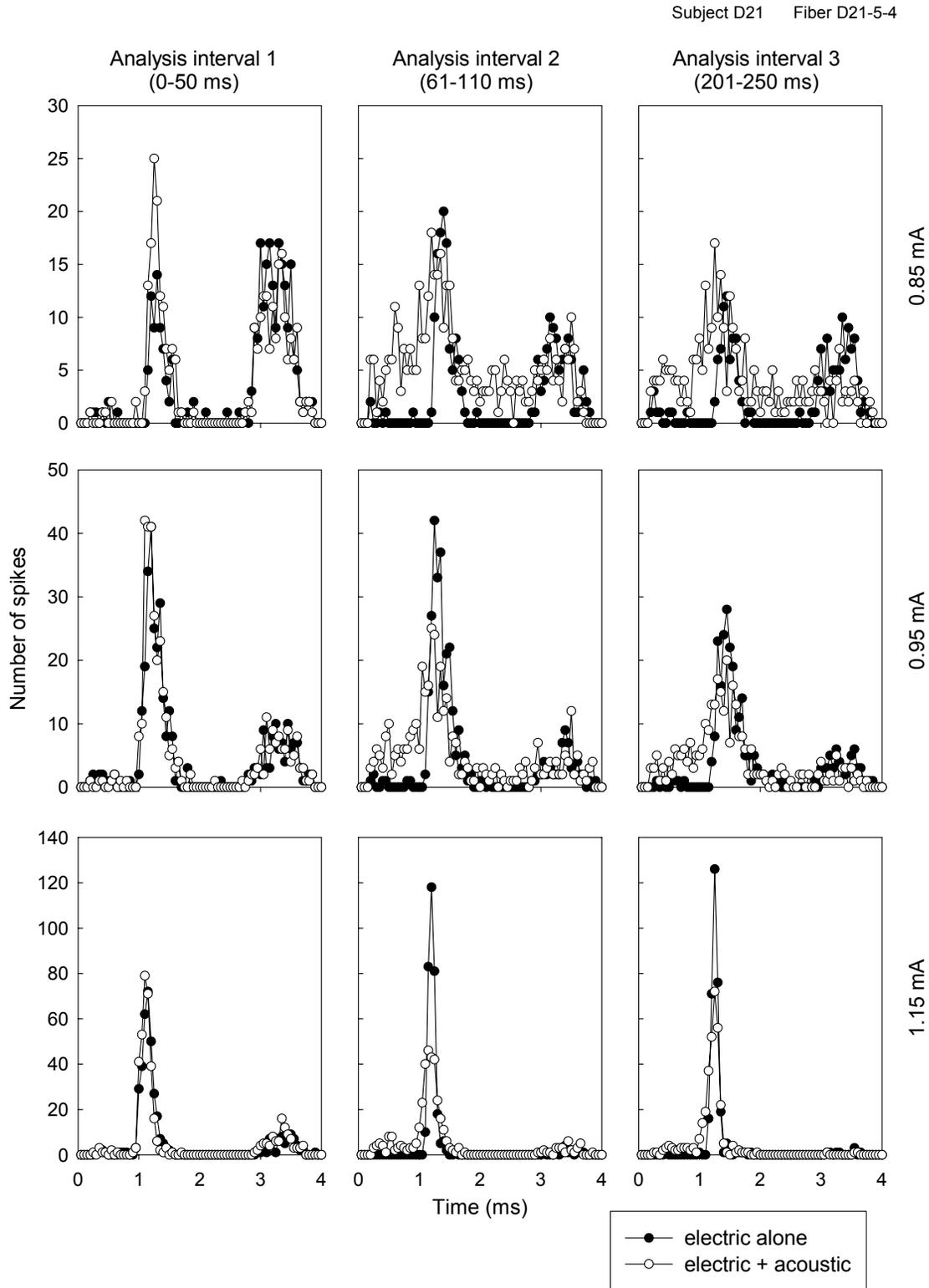


**Figure 8** Recorded traces in response to the first 12 pulses of an electric pulse train. Responses to 50 stimulus presentations are superimposed in the upper panel. Lower panel plots the spike amplitudes across the entire 400 ms pulse train.

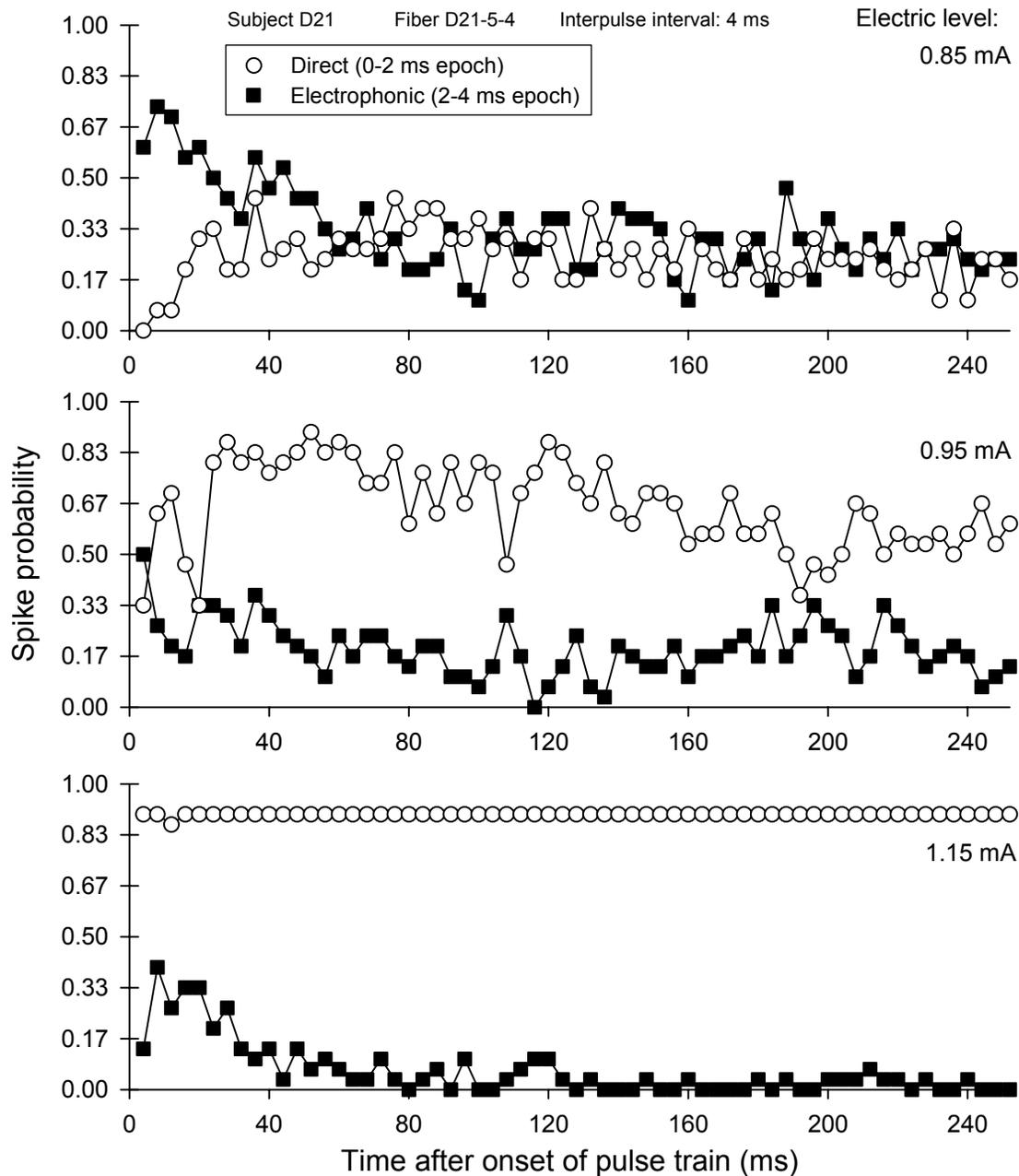
Subject D15 Fiber D15-5-3



**Figure 9** Period histograms calculated relative to the period of pulse train presentation. Each column represents responses to a different analysis interval as shown at the top of each column. Each row represents responses for a different acoustic noise level as indicated. The parameter in each graph is stimulation mode, either electric alone or electric+acoustic as indicated in the legend. Only the first 2 ms of the 4 ms period is plotted in each panel.



**Figure 10** Period histograms calculated relative to the period of pulse train presentation. Each column represents responses to a different analysis interval as shown at the top of each column. Each row represents responses for a current level as indicated. The parameter in each graph is stimulation mode, either electric alone or electric+acoustic as indicated in the legend.



**Figure 11** Spike probability is plotted as function of time relative to the onset of a pulse train. Data are the same as that for which period histograms are plotted in Figure 10. In this figure we have separated the probability of a spike occurring with a latency of less than 2 ms relative to that greater than 2 ms. Each panel plots the response probability for a different stimulus level as indicated.

### **3. Plans for the seventh quarter**

In the next quarter we plan to:

1. Continue data collection and analysis of single fiber experiments described in this QPR. Data collection relative to different noise burst and electric pulse train durations as well as effects of low level noise will be a priority in future data collection. Also, in fibers with a clear electrophonic response, particular care will be taken to collect data at different current levels to further investigate trade-offs between direct and hair-cell mediated responses.
2. We will also continue with data collection and analysis of data obtained using single-electric pulses with and without presentation of acoustic noise bursts. These experiments are being performed with guinea pig ECAP measures to provide a contrasting paradigm with no electrical adaptation.
3. We plan to begin preliminary data collection assessing bilateral interaction effects for both acoustic and electric stimulation.
4. Attend the Midwinter ARO meeting and present findings relative to acoustic-electric interactions in single-fiber recordings.

### **4. Presentations and Publications**

The following publication occurred during this reporting quarter:

Hu, N., Abbas, P.J., Miller, C.A., Robinson, B.K., Nourski, K.V., Jeng, F-C., Abkes, B.A., Nichols, J.M. (2003) Auditory response to intracochlear electric stimuli following furosemide treatment. *Hear. Res.* 185, (November) 77-89.

The following presentation was given during this quarter:

Nourski, K.V., Abbas, P.J., Miller, C.A., Robinson, B.K., Jeng, F. (2003) Acoustic noise affects auditory nerve responses to electric pulse trains. 33rd Annual Meeting of the Society for Neuroscience, New Orleans, Nov 8-12.

## 5. References

1. **Abbas, P.J., Miller, C.A., Robinson, B.K., Jeng, F.C., Nourski, K.V. (2003).** Effects of remaining hair cells on cochlear implant function, 4th Quarterly Progress Report, *Neural Prosthesis Program contract N01-DC-2-1005 NIH*.
2. **Hu, N., Abbas, P.J., Miller, C.A., Robinson, B.K., Nourski, K.V., Jeng, F-C., Abkes, B.A., Nichols, J.M. (2003)** Auditory response to intracochlear electric stimuli following furosemide treatment. *Hear. Res.* 185, (November) 77-89.2.
3. **Kiang, N. Y.-S., Wanatabe, T., Thomas, E.C., Clark, L.F. (1965).** Discharge patterns of single fibers in the cat's auditory nerve. Research Monograph No. 35, MIT Press, Cambridge, Mass.
4. **Miller, C.A., Abbas, P.J., Robinson, B.K. (2001).** Response properties of the refractory auditory nerve fiber. *J. Assoc. Res. Otolaryngol.* 2:216-232.
5. **Nourski, K.V., Abbas, P.J., Miller, C.A., Robinson, B.K., Jeng, F.C. (2003b).** Effects of remaining hair cells on cochlear implant function, 5th Quarterly Progress Report, *Neural Prosthesis Program contract N01-DC-2-1005 NIH*.
6. **Smith RL (1977)** Short-term adaptation in single auditory nerve fibers: some poststimulatory effects. *J Neurophysiol* 40, 1098-1111.